Ion Propulsion Subsystem Environmental Effects on Deep Space One: Initial Results Summary for the IPS Diagnostics Sensors

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Overview

The Deep Space One (DS1) mission has successfully validated the use of ion propulsion technology for interplanetary spacecraft. The NASA SEP Technology Applications Readiness (NSTAR) Project developed the ion Propulsion Subsystem (IPS) for DS1. As part of the IPS validation effort, the NSTAR Project included a Diagnostics Element to characterize the local environment produced during IPS operations and its effects on spacecraft subsystems and science instruments. An integrated, comprehensive set of instrumentation was developed and flown on DS1 as the IPS Diagnostics Sensors (IDS) subsystem. During the technology validation phase of the DS1 mission, data were collected from the IDS under a variety of IPS operating conditions. **IDS characterized the local plasma and contamination environments, electrostatic and electromagnetic noise and magnetic fields associated with IPS.**

Background

The DS1 IPS generates thrust by ejecting a beam of high-velocity (>30 km/s) xenon ions from the thruster. Ions are created within the discharge chamber of the engine via electron impact and are accelerated through ion optic grids to form the ion beam (see Figure 1). The fraction of xenon ionized in the discharge chamber is 80% to 90%. The xenon atoms that are not ionized in the discharge chamber diffuse through the grid and into space. The high-velocity beam ions and thermal-velocity atoms interact via a process referred to as resonant charge-exchange in which an electron is transferred to the beam ion from the neutral xenon atom outside of the engine. This **charge-exchange xenon (CEX)** ion is accelerated by the electrostatic potential in the region where it was created. Electrons from the neutralizer balance the electric charge due to the beam and CEX ions. **CEX ions strongly affect the chassis potential, the local contamination environment and the plasma wave noise produced by IPS.**

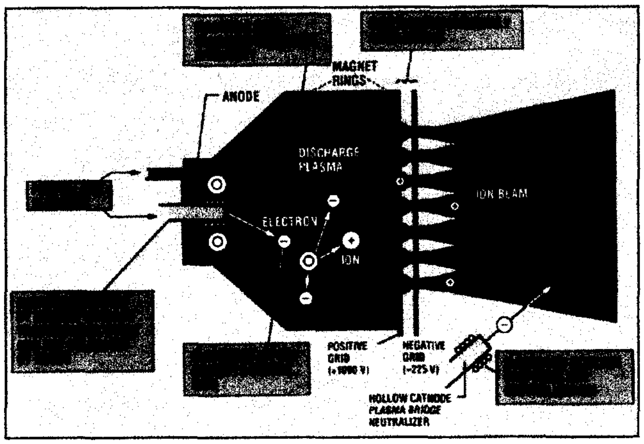

Figure 1. Principle elements of ion engine operation

IPS Effects on Spacecraft Potential

The CEX ions formed downstream of the IPS engine grids are pushed by the electrostatic potential within the ion beam plume. Some of the CEX ions are accelerated roughly perpendicular to the thrust vector. The paths of these ions are influenced by electric fields around DS1. As a result, a relatively cold (1-2 eV) flowing plasma surrounds the DS1 spacecraft. Most of the current from the ion engine is collected by the grounded thruster "mask" near the grids. The major components that affect IPS current balance are shown in Figure 2. IPS current balance establishes the spacecraft potential. IDS has determined CEX plasma ion energies (12 to 21 eV), densities (10^{12} to 10^{13} m^{-3}) and electron temperatures (1.2 to 2.0 eV). The results were used to estimate the spacecraft potential. **Depending on IPS operating conditions, the potential of the DS1 chassis is –6 eV to –10 eV with respect to solar wind "ground".** The potential causes CEX ions to follow curved paths and even "orbit" the DS1 spacecraft. Mounted on the opposite side of DS1, the Plasma Experiment for Planetary Exploration (PEPE) instrument detected CEX ions in addition to solar wind protons during IPS operations.

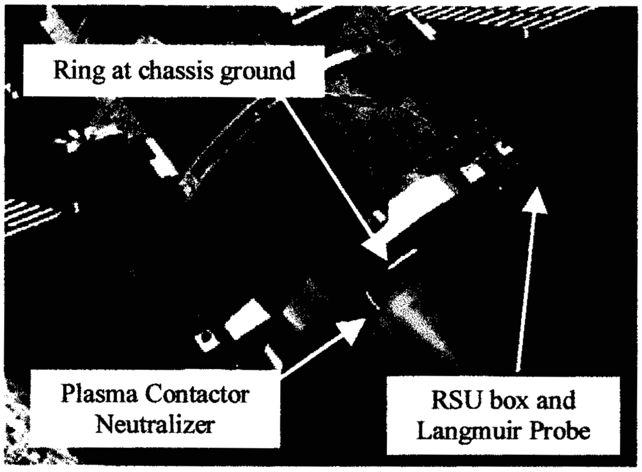

Figure 2. Major components for current balance on DS1

Contamination from IPS

Significant amounts of CEX ions are formed very near the grid, where the neutral density and beam currents are highest. These CEX ions are accelerated into the outer engine grid with sufficient energy as to physically knock atoms (molybdenum) from the grid via a process called sputtering. This leads to grid erosion, a wear mechanism that can continue until mechanical failure of the grid. The sputtered molybdenum atoms from the grid are ejected in a broad pattern from the engine and, due to their low-volatility, represent a contamination risk for sensitive surfaces on the spacecraft. The IDS has measured the contamination environment at the Remote Sensors Unit (RSU) and has found that the direct line-of-sight deposition rates of molybdenum correlate reasonably well with ground test experience (Figure 3). Non-line-of-sight transport, due to ionized molybdenum ions, was also characterized in flight, a measurement that is made difficult in ground test because of chamber effects. **The IPS logged 3500 operating hours in the first year of flight with 250 Å (25 nm) of molybdenum deposited on line-of-sight contamination monitors, whereas only 25Å accumulated on nearby sensors shadowed from direct view of the engine grid.**

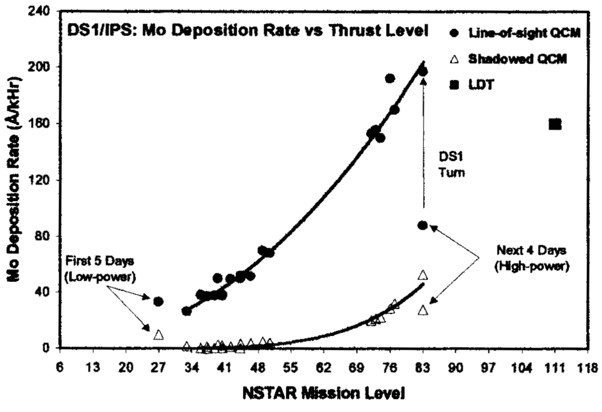

Figure 3. Mo deposition rates on line-of-sight and shadowed monitors during IPS operations

IPS-Generated Plasma Noise and EMI

Ground tests and flight experiments show that hollow cathode devices produce substantial noise in the low-frequency (<50 MHz) regime. Electrical noise produced within the discharge of the neutralizer is conducted by the CEX plasma medium. **IDS has measured the plasma noise and electromagnetic fields associated with IPS operations.** Noise spectra for selected operating levels are shown in Figure 4. Transient voltage spikes (<2 V/m) due to IPS "arcing" events are comparable to those observed for hydrazine thruster firings. The largest amplitude EMI, based on search coil measurements, is from engine gimbal actuators used for thrust vector control. The IPS plume does not affect the telecommunications link.

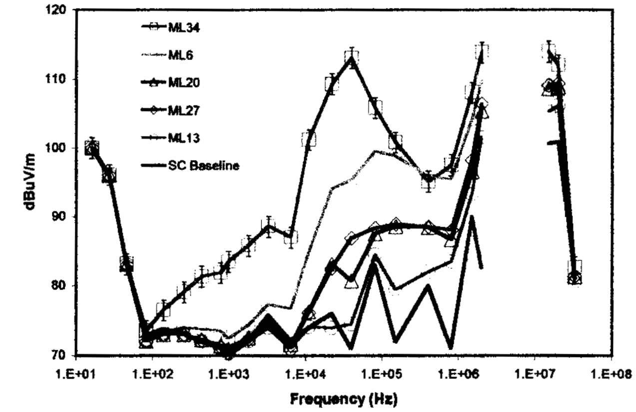

Figure 4. Plasma noise for selected IPS thrust levels

DC Magnetic Fields from IPS

The NSTAR engine utilizes rare-earth permanent magnet rings to improve the ionization efficiency within the discharge chamber. The magnetic fields from IPS are substantial (12,000 nT at 1m), and are symmetric about the thrust axis. IPS magnetic field configuration is shown in Figure 5. **IDS has determined the temperature dependence of the IPS magnetic fields.** Analysis of the residual field after temperature correction and gimbal position to assess long-term field stability is in progress. Temporal stability of the IPS field would permit background subtraction allowing external fields to be determined.

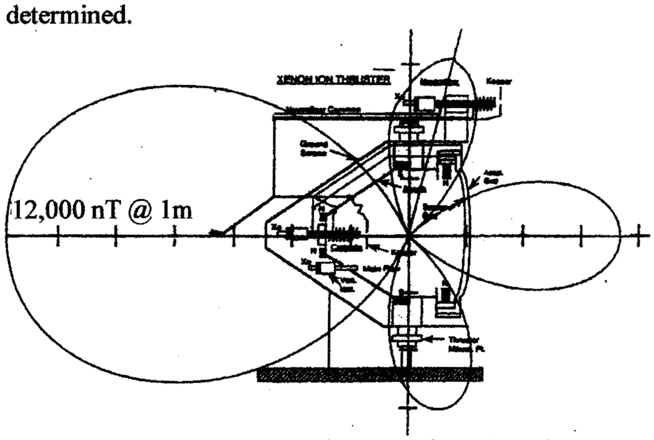

Figure 5. DC Magnetic field map for IPS engine